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EDM OF ALUMINIUM METAL MATRIX NANO COMPOSITE (AL 5056/CNT) AND OPTIMIZATION OF ITS PROCESS PARAMETERS USING WASPAS-S/N RATIO ANALYSIS

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ABSTRACT

In this paper, optimization of WEDM process parameters was focused. The optimization was done in machining of AMMNCs sample of Carbon Nano Tubes (CNT) reinforced Al 5056. Experimentations were performed as per Taguchi design of experiments for diverse combinations of process parameters like pulse on-time, pulse off-time, water pressure, peak current to study the responses such as removal rate (MRR), surface roughness (Ra), kerf width (KW) and tool wear (TW). A combined WASPAS-Taguchi S/N ratio analysis is used to investigate the effects of process parameters on responses and to identify the optimal parameter setting in EDM of AMMNC. From the ANOVA, it is indicated that Pulse on time (Ton) is most crucial input parameter followed by Peak current (IP), Pulse off time (Toff) and water pressure (WP) affecting the responses. It is observed that better results are obtained from WASPAS-S/N ratio analysis; hence it is very accurate to identify the optimum parameters analysis through the integration of methods.

KEYWORDS: WEDM Process Parameters WASPAS-Taguchi S/N Ratio Analysis, Responses & Optimization

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Original Article

1. INTRODUCTION

Aluminum Metal matrix composites (AMMCs) are being used highly in aerospace, marine and automobile industries. Machining of these composites through conventional machining scheme is hard. This is because of extreme developments in particular properties of composites. WEDM is more convenient process used for shaping of complicated contours on aluminum metal matrix composites. The working principle of WEDM is shown in figure 1. Some of the literature related to AMMCs and its machining using EDM is reviewed in the following.

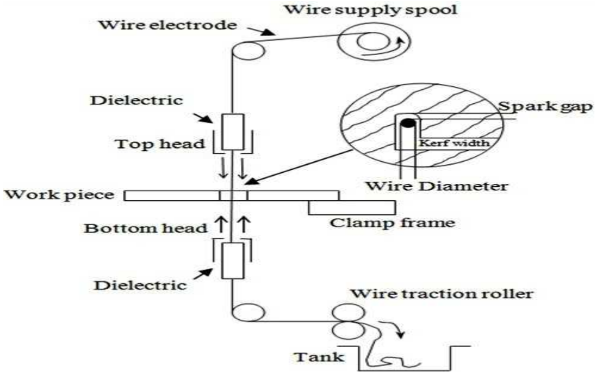

Figure 1: Working Principle of WEDM.

WEDM, also known as electric discharge wire cutting (EDWC), is a thermo electric process in which material is eroded from the work piece by a series of discrete sparks between the work piece and a wire electrode (tool) separated by a thin film of dielectric fluid (generally deionized water) that is continuously fed to the machining zone to flush away the eroded particles. The movement of the wire is controlled numerically to achieve the desired three-dimensional shapes and accuracy of the work piece. The wire is guided by sapphire or diamond guide and kept straight by a high value of wire tension, which is important to avoid tapering of the cut surface. High frequency DC pulses are delivered between the wire and work piece, causing spark discharges in the narrow gap between the two.

A stream of dielectric fluid is directed, usually coaxially with the wire, to flood the gap between the wire and work piece. The power supply for the WEDM is essentially same as that for conventional EDM. Except that the current carrying capacity of the wire i.e. limited up to less than 20 A. In addition, spark frequencies used are up to 1 MHz, to give a fine surface finish on the work piece. There is no mechanical contact between the wire and work piece in WEDM.

Sahandilya et al. [1] studied the effect of process parameters on MRR and kerf in WEDM of SiCp/6061 AlMMC. K. Kanlayasiri and S. Boonmungb [2] studied on DC53 die steel and studied the impact of machining variables on roughness of surface of wire-EDM DC53 die steel. A. B. Puri and B. Bhattacharyya [3] analyzed wire lag phenomenon in WEDM.

The geometrical inaccuracy optimized due to wire lag phenomenon in WEDM. K. Zakariaa et al. [4] investigated manufacturing of hybrid metal materials by considering optimization of wire EDM cutting parameters. L. Arunkumar and B. K. Raghunath [5] investigated the effects of current, pulse on time and pulse off time in Electric Discharge Machining performance on material removal rate and tool wear rate of Mg/SiCp metal matrix composites. Yonghua Zhao et al. [6] examined the recital of EDM carving of SiC wafers and the essential features of EDM of a SiC single crystal.

Ibrahem Maher et al. [7] examined the WEDM for refining process parameters. Cheol-SooLee et al. [8] presented an operative model to guesstimate the electrode wear of EDM. B. Naga Raju et al. [9] considered the influence of various process parameters like pulse on-time, pulse off-time, wire tension, current, upper flush and lower flush in machining of AMMCs. Some authors [10–15] done investigations to optimize the process parameters in Electrical discharge machining (WEDM) of metal matrix composite (MMCs) and other materials. Based on the contribution of different researchers, it observed that limited work has been reported on machining (EDM) of aluminium metal matrix nano composite (AMMNCs) and multi response optimization.

1.1 Applications of AMMNCs

The AMMNCs are used in many application as these possess the following features.

- Major weight savings due to strength-to weight ratio.
- Exceptional dimensional stability.
- Higher elevated temperature stability, i.e., creep resistance.
- Significantly improved cyclic fatigue characteristics.

With respect to Polymer matrix composite, MMCs offers the following advantages.

- Higher strength and stiffness.
- Higher service temperatures.

- Higher electrical conductivity (grounding, space charging).
- Higher thermal conductivity.
- Better transverse properties.
- Improved joining characteristics.
- Radiation survivability

2. EDM OF AMMNC

2.1 Material

An aluminum metal matrix nano composite work material is used in this paper for conducting EDM studies, which is prepared by reinforcing a weight percentage(1.1%) of Carbon Nano tube (CNT)material with Al5056 through stir casting process[14][15]. The composition of Al5056 and CNT particles of average size about30nm are given in table 1 and 2.

Table 1: Chemical Composition

Al 5056	Elements of Al 5056 in Percentage							
	Si	Fe	Cu	Mn	Mg	Cr	Zn	Al
	0.3	0.35	0.1	0.1	4.0	0.05	0.1	95

Table 2: Physical Properties of CNTs

Property	SWCNT (Single Walled CNT)
Thermal Conductivity (W/(m K))	6000
Electrical Conductivity (S/cm)	10^2-10^6
Specific Gravity (g/cm3)	0.8
Electron Mobility (cm2/(V s))	10^5
Coefficient of thermal expansion (K-1)	Negligible
Thermal stability in air (centigrade)	>600

2.2 Design of Experiments and EDM Experiments

Choosing process parameters is a vital step for machining in WEDM. Inappropriate assortment of process parameters leads to wire breakage, short circuit and high surface roughness. Based on the literature, the following parameters and their levels are considered for testing of this work as given in table 3.

Table 3: Process Parameters and its Levels

S. No.	Process Parameters	Symbol	Level 1	Level 2	Level 3
1	Pulse on-time (μs)	A	102	104	106
2	pulse off-time (μs)	B	42	44	46
3	Water pressure($\frac{kg}{cm^2}$)	C	0.25	0.3	0.35
4	Peak current(amp)	D	1	1.5	2

The experimental design, L9 OA (Table 4) is developed based on parameters and its levels. Experiments are conducted on developed composites according to this design using wire cut EDM for different combinations of parameters and the experimental responses such as Surface Roughness, Material removal rate, Kerf width and Tool wear rate are measured and recorded (Table 4)., the machined work piece are shown below in figure 2.

- Of the many, surface roughness is very significant parameter in machining process. The objective is to maintain the desired roughness, by that maintaining the desired quality. The surface roughness is dignified using Talysurf.

- The material removal rate (MRR) is the quantity of material that is detached per minute. MRR is affected by the type of machine along with the possessions and features of the work piece that is being cut, it is calculated by using following equation.

$$MRR = (2SG + d)tL / T \tag{2.1}$$

$$SG = (\text{ker }fwidth - d)/2 \tag{2.2}$$

where MRR = Volume of material removed/min, d= dia. of wire, Length = Total path length

t= thickness of work piece, T = cutting time in min.

- Kerf width is amount of wobble created during cutting and amount of material pulled out of the sides of the cut above the required width of the work-piece which feed in the program for cutting. After machining, obtained width is measured by microscope. Kerf width is calculated as difference between programmed widths and obtain width and it is expressed in mm.

- Tool wear terms the steady eroding of material on electrode due to steady operation. In this work, tool (electrode) is a brass material and amount of material eroded from the wire is calculated by micrometer of least count 0.0001mm. Wire diameter is measured before and after every machining experiment by micrometer. Tool wear is the difference of diameters of wire before and after machining.

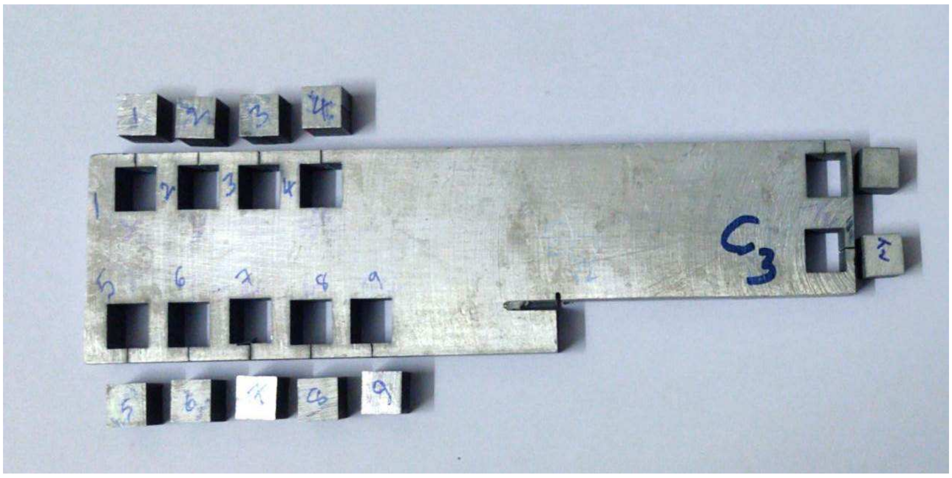

Figure 2: AMMNC Work Piece after Machining.

Table 4: Design of Experiments (OA 9) and Responses

S. No.	Ton	Toff	Wp	Ip	Ra (µm)	MRR (mm^3/min)	KW mm	TW Mm
1	1	1	1	1	0.463	0.031	0.292	0.041
2	1	2	2	2	0.421	0.038	0.330	0.058
3	1	3	3	3	0.478	0.039	0.343	0.062
4	2	1	2	3	0.488	0.041	0.349	0.038
5	2	2	3	1	0.430	0.049	0.341	0.043
6	2	3	1	2	0.638	0.051	0.326	0.072
7	3	1	3	2	0.736	0.048	0.356	0.046
8	3	2	1	3	0.587	0.056	0.341	0.052
9	3	3	2	1	0.526	0.059	0.372	0.071

3. OPTIMIZATION OF PROCESS PARAMETERS USING WASPAS METHOD

In this paper, optimization of process parameters is done in two stages, firstly by WASPAS method and secondly through Taguchi S/N ratio analysis.

3.1 Stage-1: WASPAS Method

The machining responses (Table 4) are analyzed using WASPAS method for identification of optimum machining parameters using its steps as in the following.

Steps in WASPAS Method

Step 1: Set the initial decision matrix (responses, Table 4)

Step 2: Normalize the decision matrix using the following equations:

$$\bar{X}_{ij} = \frac{X_{ij}}{\max_i X_{ij}} \text{ for maximization} \tag{3.1}$$

$$\bar{X}_{ij} = \frac{\min_i X_{ij}}{X_{ij}} \text{ for minimization} \tag{3.2}$$

Normalized values (Table 5) are calculated for each response the using equation 3.1 and 3.2 for maximization (response MRR) and minimization (responses Ra, KW, TW) respectively.

Table 5: Normalization Values

Exp. No.	Ra	MRR	Kerf Width	Tool Wear
1	0.90929	1.76769	1	0.92683
2	1	1.56414	0.88485	0.65517
3	0.88075	1.74247	0.85131	0.6129
4	0.8627	1.24546	0.83668	1
5	0.97907	1.75269	0.8563	0.88372
6	0.65987	1	0.89571	0.52778
7	0.57201	1.06835	0.82022	0.82609
8	0.71721	1.27468	0.8563	0.73077
9	0.80038	1.24149	0.78495	0.53521

Step 3: Determination of Weights for the Responses

The weights for each response are evaluated using the equations 3.3, 3.4 and 3.5, values are given in table7 by processing the Pij data (Table6)

w_j is the weight of the jth criterion

$$P_{ij} = \frac{X_{ij}}{\sum_{i=1}^{m} X_{ij}} \text{ is normalized matrix} \tag{3.3}$$

Entropy value e_j

$$e_j = -k\sum_{i=1}^{m} P_{ij}\ln(P_{ij}) \tag{3.4}$$

here $k = \dfrac{1}{\ln(m)}$, m = 9

$$W_j = \frac{(1-e_j)}{\sum_{j=1}^{n}(1-e_j)} \tag{3.5}$$

Table 6: P_{ij} for Responses

Exp. No.	Pij for Ra	Pij for MRR	Pij for KW	Pij for TW
1	0.097126	0.084707	0.095738	0.084886
2	0.088316	0.095731	0.108197	0.120083
3	0.100273	0.085933	0.112459	0.128364
4	0.10237	0.120225	0.114426	0.078675
5	0.090203	0.120225	0.111803	0.089027
6	0.133837	0.149736	0.106885	0.149068
7	0.154395	0.140156	0.116721	0.095238
8	0.123138	0.117469	0.111803	0.10766
9	0.110342	0.12061	0.121967	0.146998

Table 7: Weights for Responses

Response	Weightage
Ra	0.187318
MRR	0.534877
KW	0.170525
TW	0.10728
Sum	1

Step 4: Calculation of Weighted Sum (Q_1) and Weighted Product (Q_2) Values

In WASPAS method, two criterion are used. The first criteria of a mean weighted sum is calculated regarding total relative importance of i^{th} using Equation 3.6.

$$Q_i^{(1)} = \sum_{j=1}^{n} \bar{X}_{ij}.W_j \tag{3.6}$$

The total comparative significance of the i_{th} alternative is calculated for mean weighted product using the Equation.3.7.

$$Q_i^{(2)} = \prod_{j=1}^{n} \bar{X}_{ij}.W_j \tag{3.7}$$

Step 5: Calculation of Wasspas Grade (Q)

Equation 3.8 gives a subjective accumulation of additive and multiplicative values. This metric is referred as Wasspas Grade.

$$Q_i = 0.5Q_i^{(1)} + 0.5Q_i^{(2)} \tag{3.8}$$

$Q^{(1)}$, $Q^{(2)}$ and Q are calculated using the Equation 3.6, 3.7 and 3.8 respectively and are shown in table 8.

Table 8: Weighted Aggregated Values of WASPAS

Exp. No.	$Q^{(1)}$	$Q^{(2)}$	Q	Rank	S/N Ratio
1	1.38578	1.321466	2.707246	1	8.65056
2	1.245117	1.188919	2.434036	4	7.72654
3	1.307909	1.213203	2.521113	3	8.03184
4	1.077724	1.061134	2.138858	5	6.60364
5	1.361697	1.29236	2.654057	2	8.47820
6	0.867844	0.847714	1.715558	9	4.68811
7	0.907076	0.883768	1.790844	8	5.06115
8	1.040562	1.007475	2.048038	6	6.22676
9	1.005239	0.966222	1.971461	7	5.89577

After calculating average WASPAS grade values (Q), the best parameter combination A_1 B_1 C_1 $D_1$is determined, which is corresponding to the higher average WASPAS value represents better quality.

3.2 Stage-2: Taguchi S/N Ratio Analysis

There are few methods which aim to find the best combination of parameters which has lowest variance. Taguchi's method is one such popular method. SNR measures how the response varies relative to the nominal or target value under different noise conditions. Here, Taguchi S/N ratio analysis is conducted on average WASPAS index values to determine the optimum parametric values using Minitab software (Table 9). The main effect plot obtained from Minitab is shown in figure 3. The optimum parameters combination obtained from this analysis (Figure 3) is $A_1B_2C_3D_1$ which is corresponding to higher means of S/N ratios. The S/N ratios of WASPAS grade are given in table 8.

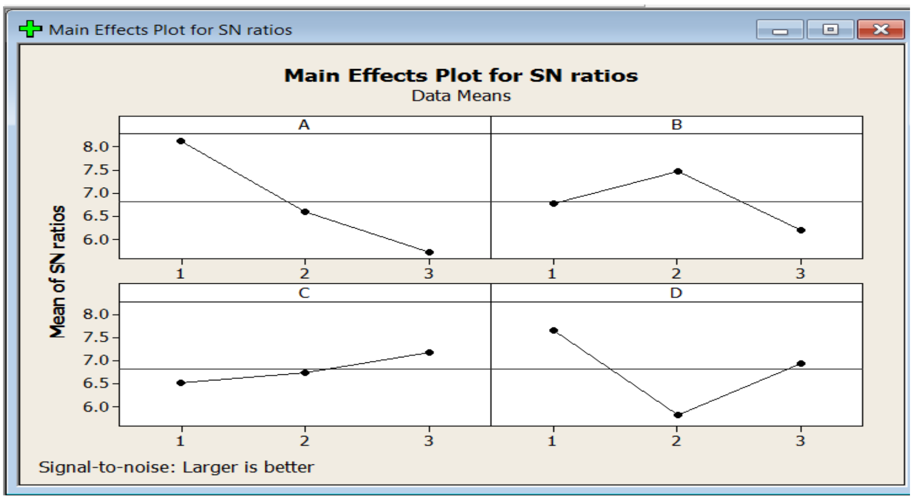

Figure 3: S/N Ratio Plots.

Table 9: Optimal Parameters and Order from S/N Ratio Analysis

Level	A	B	C	D
1	8.136	6.772	6.522	7.675
2	6.590	7.477	6.742	5.825
3	5.728	6.205	7.190	6.954
Delta	2.408	1.272	0.669	1.850
Rank	1	3	4	2

4. CONTRIBUTION OF PROCESS PARAMETERS ON RESPONSES

Contribution of process parameters towards responses are determined by performing ANOVA on WASSPAS grade using MINITAB software and results are shown in table 10. It is observed that Pulse on time (A), pulse off time (B), Water pressure (C), Peak current (D) affect the compound responses by 53.07%, 13.09%, 29.51% and 4.33% respectively. The percent numbers depict that the Pulse on time, Peak current significant effect on responses.

Table 10: ANOVA of WASPAS Grade

Parameter	DF	SS	MS	F	P	% Contribution
TON	2	0.58322	0.29161	3.67	0.057	53.08
TOFF	2	0.14381	0.07190	0.73	0.502	13.09
WP	2	0.04760	0.02380	1.75	0.215	4.33
Ip	2	0.32423	0.16211	0.59	0.572	29.51
Error	2	0.02160	12453.75		1.7393	
Total	10	1.09886				

5. COMPARISON AND VALIDATION OF RESULTS

The optimal parameter setting obtained from combined WASPAS- S/N ratio method is confirmed experimentally and compared with the confirmation results of the parameter setting corresponding to higher WASPASS grade as given in table 11. From the results, it is evident that the combination obtained WAPAS- S/N ratio method gives best result.

Table 11: Confirmation and Comparison of Results

Criteria	Higher WASPAS Grade	WAPAS- SNR Method
Optimal parameter setting	$A_1B_1C_1D_1$	$A_1B_1C_3D_3E_3$
Ra (μm)	0.463	0.42
MRR (mm^3/min)	0.031	0.031
Kerf Width(mm)	0.292	0.277
Tool wear(mm)	0.041	0.039

6. CONCLUSIONS

In this paper, WASPAS-Taguchi S/N ratio analysis is utilized to investigate the effects of process parameters on multi responses and to determine the optimum parameter setting in EDM of developed AMMNC. The following conclusions are derived from the results of the present work.

- In the present work, parameters of wire EDM have been optimized for obtaining higher MRR and lower surface roughness, kerf width, tool wear values. From the ANOVA, It is indicated that Pulse on time (Ton) is most crucial input parameter followed by Peak current, Pulse off time and water pressure.
- It is observed that better results are obtained from WASPAS-S/N ratio, hence it is very accurate to judge the optimum parameters based on obtained results of S/N Ratio analysis through integration.

This work will be extended by considering further more EDM process parameters with wider range and different AMMNCs to study its influence on multi responses.

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